In 2006, the former Director of the National Institutes of Health, Elias Zerhouni, expressed hope that, thanks to the power of medical imaging, there would no longer be the need for open surgery in 25 years' time. In oncology, radiotherapy is getting ready to fulfil his vision.

Conventional radiotherapy mainly aims at tumour infiltration, while open surgery is added to control the bulky local tumour volume. New radiotherapy will control both tumour infiltration and the bulky tumour by accurately painting the required dose to sterilise the tumour, sparing organs at risk. To be able to perform such dose painting, the tumour needs to be extremely accurately positioned with respect to the treatment beam.

In recent years, cone beam CT has been integrated into radiotherapy treatment systems. This use of the cone beam CT on the linac is providing treatment guidance based on bony structures and implanted fiducial markers. With these cone beam CT-linac systems, great success has already been realised in the minimal invasive treatment of prostate tumours, body stereotactic treatment of lung tumours and stereotactic treatment of tumours of the brain. For these tumours, there is already a clear trend of less fractionation, better targeting with less normal tissue involvement, and thus less toxicity and surgery.

**MRI for the guidance of radiotherapy**

During the last two decennia, MRI has caused a revolution in diagnostics. Its excellent soft tissue contrast makes MRI extremely well suited for oncology, both to define the geometry of the tumour process and to characterise its functional information. The increasing field strength (from a standard of 0.5T a decennium ago to the present standards of 1.5 and 3T, with experimental systems at 7T), combined with better imaging gradients, multichannel RF technology and the continuously improving sequences, makes MRI the standard for stationary locations, such as the brain. Current developments in special image sequences using breath hold, cardiac gating and ultra-fast sequences, also make MRI the standard for those body locations dominated by breathing, cardiac, bowel and bladder related motions (Fig. 1).

Now it is time for the expansion of this diagnostic revolution in MRI towards real-time and online therapy guidance in oncology, a revolution from the bony structure related cone beam CT to high-quality, soft tissue-based, real-time MRI. The clinical introduction of MRI-guided brachytherapy is already fully in progress. An example is the great success of Embrace, the European study on MRI-guided brachytherapy, a breakthrough therapy of tumours of the cervix. The extremely high local tumour control achieved is indicative of this new role of MRI-guided radiotherapy.

For MRI guidance of external beam radiotherapy, the MRI linac is under development at our department (Fig. 2). The present prototype MRI linac is a 6MV radiotherapy accelerator.
surrounding a 1.5T diagnostic quality MRI. This combination provides high-quality, real-time MRI guidance, at better than 1mm geometrical accuracy, during the actual irradiation itself. The MRI linac concept will be made commercially available by Elekt and Philips.

Due to the enormous targeting accuracy, the system will be able to provide the required dose painting in tumours at all locations in the body, for example tumours of the rectum, the oesophagus and kidneys (these tumours are presently not very treatable with radiotherapy due to their mobility and/or limited CT visibility). In addition, the system will provide better radiotherapy, with better sparing of organs at risk, for regular radiotherapy applications, such as tumours of the prostate, breast, and head and neck. The clinical expectations are of better local tumour control, minimal invasive therapy with less toxicity, omitting the necessity of surgery to control the macroscopic tumour, thus fulfilling the vision of Elias Zerhouni.

**Personalised cancer care**

MRI guidance will start a paradigm shift in therapy: the central position will become MRI, not knowledge of fractionated radiation and radiobiology. This soft tissue MRI for guidance will be extended, with functional information of the tumour obtained with advanced MR, PET and SPECT imaging. The use of endogenous contrasts will assist both tumour characterisation and better delineation (Fig. 3). Imaging must be verified by pathology studies in close collaboration with surgery. MRI guidance for therapy will be the full advanced imaging implementation of the personalised cancer care concept.

**Will radiotherapy again merge with radiology?**

As a consequence of MRI therapy guidance, radiotherapy becomes more of an interventional radiology process. Close collaboration is needed between the radiation oncologist, radiologist, pathologist, medical physicist and surgeon. Such a multidisciplinary team will guide the care of those oncology patients with local disease. At the centre of this process is, of course, the patient, but also the personalised imaging in all the different treatment processes: diagnostics, image-guided biopsies, treatment and response assessment.

A major design problem is to define the clinical procedures on how to execute these treatments, training radiation technologists, radiation oncologists and radiologists. There is a central role for medical physicists, who will develop their profession from QA and safety specialists towards optimal therapy guidance of individual patients, with shared responsibility with clinicians and technologists.

Advanced image guidance will also broaden treatment options, aside from radiotherapy, the rise of MRI-guided HIFU, RFA and other ablation techniques will gain importance in the local treatment of tumours.

MRI guidance is essential in treatments and where therapies are not under full MRI control they must be considered with great care, for example conventional RFA and also radiotherapy with protons. Hence, proton radiotherapy for high precision applications must also become MRI-guided; conventional proton systems will fail in competition with these new MRI-guided technologies.

**Treatment response assessment**

MRI guidance also offers a better evaluation of the treatments. Studies can be designed at a higher knowledge level, not just randomisation between two treatment options, but learning how treatments really work by correlating the exact 3D dose accumulation in the actual anatomy, with treatment outcome. It will be clear that extensive follow-up imaging is a prerequisite.

**Implementation**

The UMC Utrecht is building an international consortium that includes academic centres from Europe, the US and Canada. Huge investments are needed both in the equipment and the development of MRI sequences and treatment procedures. Because a whole new multidisciplinary profession has to be built, great efforts are needed to build the international knowledge platform: training, clinical procedures, protocols, QA, safety, etc.

**Conclusion**

The potential impact of the MRI-guided treatments will be minimal invasive local tumour treatment with high local control.

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**Fig. 3: Characterisation of the individual lymph nodes location with breast tumours. T2 weighted Fast Field Echo (T2-FFE) visualisation of the lymph nodes in the axillary, periclavicular and the deep cervical region.**

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